United Services Section

President—Sir CECIL WAKELEY, Bt., K.B.E., C.B., F.R.C.S.

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Submarine Medicine on U.S.S. Nautilus and U.S.S. Seawolf

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INTRODUCTION

IN the past few years the highly specialized field of submarine medicine and submarine physiology has been deeply involved in the revolutionary changes brought about by the advent of the nuclear submarines, "Nautilus" and "Seawolf". To-day there is more than promise that the problems of nuclear power will involve all fields of military medicine and this is not limited to military medicine alone, for the application of nuclear energy for civilian power, already in being in the United Kingdom, promises to bring these problems to civilian medical practitioners, particularly in the field of industrial medicine. While some of the problems met on "Nautilus" and "Seawolf" are limited to submarines because of their unique operational environment, many others apply equally to all reactor installations, either military or civilian, sea-going or shore-based. The experiences that submarine medicine has had in these initial years may, therefore, be justifiably utilized for a realization of the part that medicine will play in the nuclear age.

There are three important areas in which nuclear propulsion has strikingly added scope and depth to the field of submarine medicine. The first of these is a result of the new environmental situation created by reactor propulsion—an environment which bears little similarity to that of the conventional submarine. While understandable, it is erroneous to think of the medical problems of nuclear submarines as being a simple continuum of previous submarine problems to which has been added the factor of nuclear radiation. The environment of the true submersible, its effects and its control under prolonged submergence, represent a really new and unique entity, and radiation is but one of many factors.

The second significant change in submarine medical practice aboard a nuclear submarine lies in the necessity for strict supervision of radiation control measures during in-port periods. For the most part medical and toxicological problems of previous submarines have been minimal during in-port periods of maintenance. In contrast, in nuclear submarines, radiation control measures have actually greater significance during such periods than while at sea. It is during this time that reactor shield integrity may be broken in order to allow workmen access to the reactor system and to allow work on contaminated components in areas of radiation flux. Medical personnel must therefore be on the *qui vive* during any such period until the operation is completed in order to control exposure and to insure against spread of contamination. In quantitative terms, if alertness may be so quantitated, approximately four times more attention is required, based on relative exposure during maintenance as compared to that at sea.

The third, and perhaps most important, factor that has expanded the boundaries of submarine medicine is that on nuclear submarines a medical officer is directly assigned as a crew member, and is on board for all operations. Evaluation of the medical problems, therefore, no longer depends upon short term on-board observations in a guest capacity. The full impact of this intimacy is only beginning to be realized, but it can be assumed certainly that definition of the manifold problems cannot help but be improved. The rapid "break-throughs" in nuclear technology and the acceleration of new developments demand such intimacy for optimum results and maximum benefit to the submariner, whose health and efficiency are the prime interest of submarine medicine. This opportunity for daily, intimate, and long-term contact with the submarine and its problems may perhaps be ranked as the most important development in submarine medicine since its inception.

While this paper deals primarily with the radiation problem on nuclear submarines, it is necessary in introduction to re-emphasize the point that nuclear power represents more than just a radiation problem to submarine medicine. It is basically a study of the effect of a novel environment on the human organism.

THE SUBMARINE ENVIRONMENT

It has been stated previously that the nuclear submarine environment is unique; it is necessary, however, to reiterate this point, for it profoundly affects radiation control technique and, indeed, provides a leitmotiv in the formulation of the radiation hygiene programme.

The single most important factor in the environment with which we deal on nuclear submarines is the capability for long submergence independent of the Earth's atmosphere. All previous submarines have been dependent upon air, save for relatively short periods, rarely exceeding twelve hours, at which time contact with the Earth's atmosphere was re-established. Once on the surface fresh air was circulated in the ship to dilute and displace toxic atmospheric elements accumulated in the ship during its submerged period.

Surfacing of the submarine at that time was required to run diesel engines, which, in turn, charged the electric storage batteries which propelled the ship when submerged. Operation of such diesel engines is an aerobic process—the combustion of oxygen and a fossil fuel.

The diesel snorkel has not significantly changed this situation for the snorkel tube, carrying air to the submerged submarine for her diesels, also carried fresh air to the ventilation system and to the crew as a secondary effect. Snorkelling must, therefore, be considered as a simple variant of full surface operations in which communication with the open atmosphere is maintained although the ship is submerged.

The impact of nuclear power lies in the fact that splitting or fission of the uranium atom to furnish heat for the production of steam is an anaerobic process—indeed, for technical reasons, oxygen must be excluded from the process. Given this as the basis for a propulsion system, rather than oxygen-dependent diesels, true submersible capability is achieved.

Visualize such a true submersible as a streamlined capsule operating beneath the ocean's surface. This microcosm, this sub-miniature world, must maintain an independent atmosphere and an ecology compatible not only with life, but with efficient combat life for the the personnel contained within it. A most important limiting factor in this ecology is that such an atmospheric volume is contained and finite; therefore, little atmospheric dilution of any toxic air-borne substance can be expected. We will see later how this relates particularly to the control of air-borne radioactive contamination.

In such an environment three basic conditions must be met in order to support life:

(*a*) Continuous supply of oxygen to maintain normal atmospheric concentrations.

(*b*) Continuous removal of normal human metabolic products, i.e. carbon dioxide.

(*c*) Prevention of or provision for removal of any toxic substance released by ship's equipment.

As a corollary to these a vigorous and continuing study must be made of atmospheric conditions aboard to detect and quantitate new toxic elements. Experience has shown that many of the so-called "new" elements have existed previously in conventional submarines, but were either not recognized or were quite properly disregarded, since significant concentration values were not obtained with the limited submergence times of the pre-nuclear period.

Many traps await the unwary in trying to forecast presence or degree of importance of a given toxic substance in such a finite environment. An example is that of carbon monoxide, the production of which was previously linked chiefly to diesel exhaust fumes. With the passing of diesel propulsion one might expect this problem to be minimized. On the contrary, tolerance concentrations (100 parts per million) have been reached within thirty hours submerged on nuclear submarines. The chief source now is tobacco smoke, a source not previously emphasized, yet of extreme importance with longer periods of submergence.

Another example of an apparently harmless product giving rise to trouble in this new environment is the evolution of radioactive radon gas originating from luminescent radium-painted markers. It has been standard practice for many years in our submarines to use radium-painted markers and dials for emergency illumination. Such radium, of course, will produce its radioactive daughter-gas, radon. Gaseous radon diffuses easily from apparently well-sealed components and enters the ship's atmosphere. Here it proceeds to decay into a long series of radioactive daughter elements which become associated with dust particles suspended in the air. They are then easily collected by the filtration devices which operate constantly to monitor the air for air-borne radioactivity. Fig. 1 shows a rather dramatic increase in air-borne beta activity with time submerged as the result of only six small radium-painted switch markers being present on the submarine. Note the abrupt increase in air activity after submerging—a factor of more than ten in twenty-four hours. The curve shows the gradual levelling off as equilibrium is approached in about forty-eight hours. At equilibrium, levels are about thirty times higher than when surfaced. Apart from possible biological hazard this represents a serious nuisance because radiation monitoring equipment does not distinguish between such increases due to radon and that due to the much more serious condition of a reactor system leak. One would be justifiably quite concerned by such an increase if due to a reactor system leak. It is, therefore, necessary to initiate an immediate and complicated identification technique whenever such increases occur. The only solution is to remove all such radium sources from the ship, and, indeed, from the entire navy supply system to avoid their reappearance on board. The lower interrupted curve in Fig. 1 shows the increase in air activity over a similar period after removal of the six small markers. The remaining concentration is chiefly due to the radium-painted dials on the wrist watches of crew members.

These problems, and others like them, have been solved for the most part by removal of the offending source, by insistence on more rigid leak tightness requirements in systems containing toxic materials or by substitution with less toxic materials, and by development of removal systems such as the CO_2 scrubber. In the design of removal equipment medical personnel have a vital contribution to make. They must furnish the design engineer with the desired allowable concentration of the toxic substance. In the case of carbon dioxide, for example, it is not feasible to build equipment which will sustain zero concentrations; a

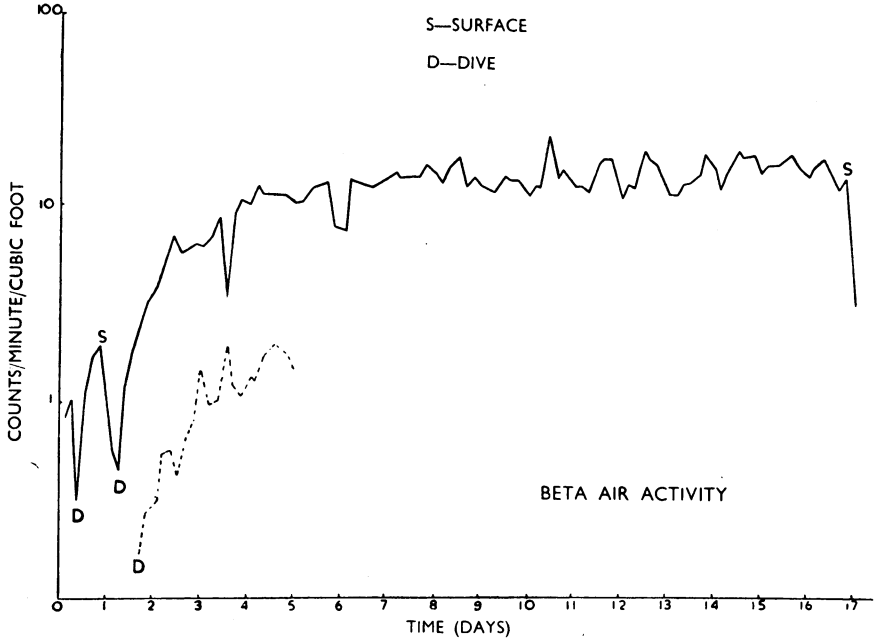

FIG. 1.—Radioactivity due to radium-painted markers.

compromise tolerance concentration must be used. Such tolerance concentrations, however, cannot be based on standard tolerances in the literature which apply usually to the eight-hour day, five days per week exposure time of industry. Aboard submerged submarines, where a 24 hours per day exposure is the case, lower tolerance limits must be applied. This principle equally is related to maximum permissible values for radiation levels as well as for toxic gases. It is, thus, one of the prime missions of submarine medicine to establish such limits by investigation and research and to communicate them to the design engineer.

The environmental factors at work here may equally apply to space medicine, and indeed, in many respects, one might simply substitute "space ship" for "submarine" in this discussion.

Radiation in the Submarine Environment

Radiation hygiene in a submarine, an environment radically different from that of land-based reactors, presents the necessity of adapting and modifying standard control techniques. In many respects this novel environment is hostile toward efficient radiation hygiene. The following five factors, for example, will all operate to increase the shipboard radiation control problem:

(1) The closed atmosphere of a submersible allows for little dilution of air-borne radioactivity by dispersion in air.

(2) Lack of space for such requirements as decontamination stations and control areas.

(3) Proximity of living, eating, and food preparation areas to an operating reactor system with an ever-present potential contamination hazard.

(4) The submariner's work week, which is a seven-day week with no possible off-site recuperation from exposure.

(5) The constant and relatively rapid re-circulation of air through the ship's ventilation system when submerged allows for rapid spread of air-borne radioactivity from one spot to another.

If, however, one examines a submarine more closely there are many inherent factors, particularly in its architecture, that will tend to assist radiation control. First of all, the submarine is arranged horizontally like a long sealed tube. The reactor compartment section of the tube, the chief source of radiation, can affect personnel only within the compartment itself or immediately forward and aft of it. Shielding is thus simplified and the advantages of locating living areas with zero radiation levels either well forward or aft of the compartment, exploited. As far as the crew is concerned shielding in three planes only is vital, and full circumferential shielding of the system is not necessary.

An additional important factor is that our sealed tube is horizontally divided into a series of compartments by stout watertight bulkheads. This allows for rapid isolation of a given contaminated compartment simply by shutting a watertight door and securing ventilation to that area. In the case of the reactor compartment, ventilation supply and exhaust lines pass through the compartment without openings into it. Since this is the potential area of contamination, pick-up by the ventilation system can be avoided. (Fig. 2).

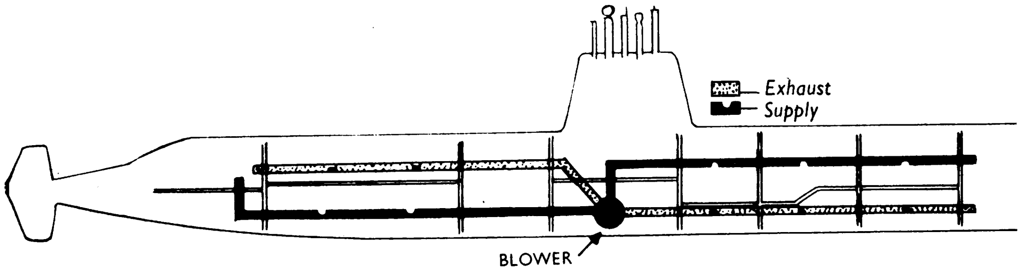

FIG. 2.—Submarine compartmentation and air recirculation.

Additional helpful factors are the small number of personnel in a submarine crew, which allows for ease of communication and control, and lack of multiple exits and entrances that must be guarded by monitoring stations in an industrial plant.

These advantages and disadvantages can be manipulated into an effective shipboard programme. For example, contamination control is built around the compartmentation system and its ease of isolation; occupancy of the reactor compartment is held to a minimum by placing master controls outside this area; contamination casualty regulations require rapid shutdown of the re-circulating ventilation cycle; protective clothing is dispersed fore and aft of the engineering spaces for accessibility.

Apart from control techniques themselves, considerable adaptation of radiation equipment is also necessary and laboratory techniques used on board must be modified to meet the peculiar environmental situation of a submarine. Radium calibration sources are prohibited due to the radon problem mentioned previously and cobalt 60 is substituted as a calibration source. Again, because of the explosion hazard and high oxygen consumption, open flames cannot be tolerated and evaporation of liquid samples must be done by infra-red lamps. Evaporation of large twenty-four-hour urine samples as a check on ingested activity is prohibited for æsthetic reasons in the confines of a submerged submarine, and must await an in-port period. At sea it would be done only on an emergency basis with an assured lowering of the popularity of medical department personnel among the crew. Volatile solvents in radio-chemical techniques must similarly be avoided. All radiation-measuring equipment must be rugged enough for use on board an operating combat ship, a requirement which, surprisingly, disqualifies many devices used in a shore-based installation.

One interesting technique modification is in the use of an end-window Geiger-Mueller tube for counting of liquid samples. In this a carefully measured 50 ml. aliquot of the liquid, usually reactor coolant water, is placed in a standard metal cup. The cup is positioned on a shelf beneath the Geiger tube. Accurate positioning of the cup in relation to the tube is important and is carefully checked with standard spacers and positioning pins. Under these fixed geometrical conditions the number of counts per minute obtained by counting the sample may simply be referred to a predetermined calibration curve of counts per minute versus microcuries per millilitre. If the calibration curve is based on an isotope whose energy approximates that of the sample very accurate results can be obtained to a level of 1×10^{-5} microcuries per millilitre. This is a simple, rapid technique and has the advantage of quickly being taught to untrained personnel. It was soon observed that in rough seas spillage from the cup would result from this procedure. Under such conditions the cup is covered with a thin film of Saran wrap, a cellophane-type material held firmly in place by a metal lip or rim which fits over the cup. Sensitivity loss when utilizing this is 10%, a reduction to 1×10^{-4} microcuries per millilitre as the lower limit of detection.

These are only a few of the necessary modifications to standard techniques, and, as in the case of radiation control procedures, the submarine milieu is all-important in determining the degree and type of modification necessary.

THE REACTOR

Before discussing the personnel exposure problem aboard nuclear submarines it is necessary to describe the reactor system.

A water-cooled reactor may be considered simply as a collection of uranium atoms. Bombarded by neutrons, the uranium atoms fission, or split, and release a tremendous amount of radiation and kinetic energy as heat, which can be removed by water flowing through the reactor lattice. The two atomic fragments remaining after the parent uranium atom is split are the fission daughters, and are intensely radioactive, emitting both gamma and beta radiation. These fission daughters cause *residual reactor radiation* long after the reactor is shut down. The reactor, then, is responsible both for prompt fission radiation (gamma and neutron) and residual radiation (gamma and beta). These are not the only sources of radiation for the reactor as it operates produces high levels of neutron radiation in its vicinity. These reactor neutrons will activate stable non-radioactive atoms present in the coolant water flowing through the reactor lattice.

As water flows through the reactor the temperature of the water is raised by the fission process and this heat, in turn, is transferred to a steam generation system through a heat exchanger or boiler. The reactor coolant water leaving the heat exchanger is then propelled back through the reactor by a pump. This closed cycle operation of coolant water is illustrated in Fig. 3. There are two important points to note about this system—first, the

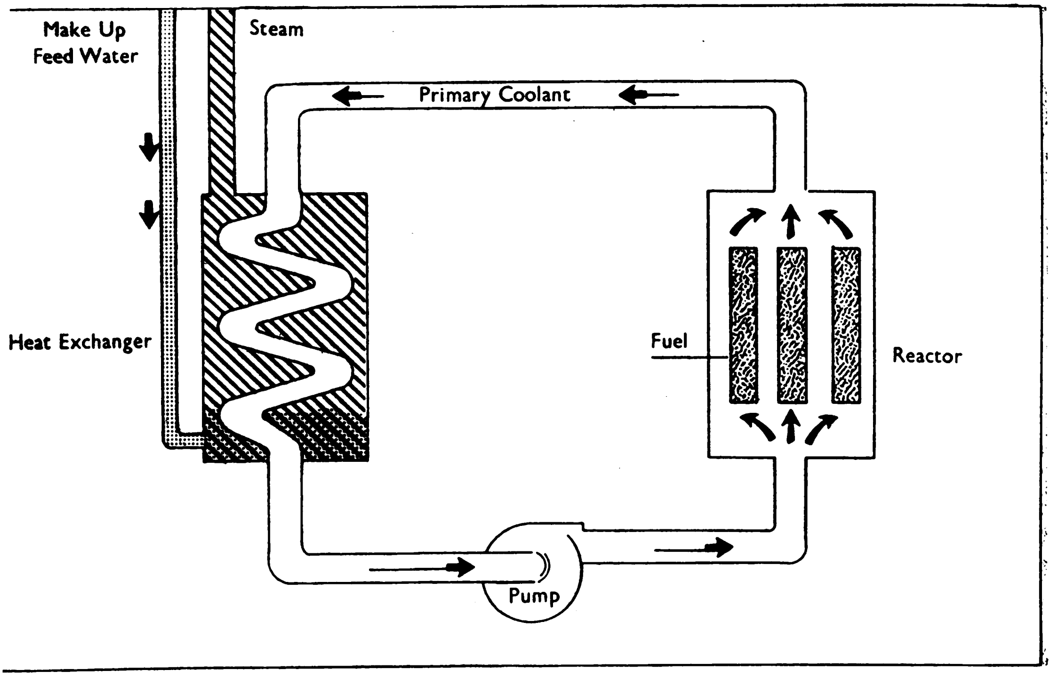

FIG. 3.—Basic reactor system and coolant cycle.

piping carrying this coolant water is leakproof; secondly, the steam generated in the heat exchanger is not radioactive. Note that the radioactive coolant water "sees" the steam only through the walls of the heat exchanger; there is no direct contact between radioactive water and the steam. This steam can thus be easily transferred from the reactor area without shielding and can be used to turn a conventional steam turbine.

Circulating in the coolant water are the neutron-activated radioactive atoms we have mentioned previously. The metallic radioactive atoms will tend to stick on the inner surface of the piping, an important phenomenon, having an effect both in raising radiation levels in the area, and in necessitating precautionary measures for contamination control whenever the system piping is opened. These radioactive atoms in the system piping continue to radiate after the reactor is shut down, and they are chiefly responsible for the gamma radiation levels in the compartment at that time. The residual fission radiation from the fission daughters in the reactor itself, being well shielded, makes little contribution. In the case of the longer-lived radioactive atoms in the coolant water, there will tend to be increasing build-up with time so that static conditions will not be met in regard to radiation dose in this area, but will tend to increase.

The compartment containing the reactor system is a section of the submarine termed the reactor compartment. This compartment, essentially a right cylinder, is divided horizontally by a deck forming an upper and lower reactor compartment. The deck is actually a thick shield, below which is placed the reactor and all the coolant system (Fig. 4).

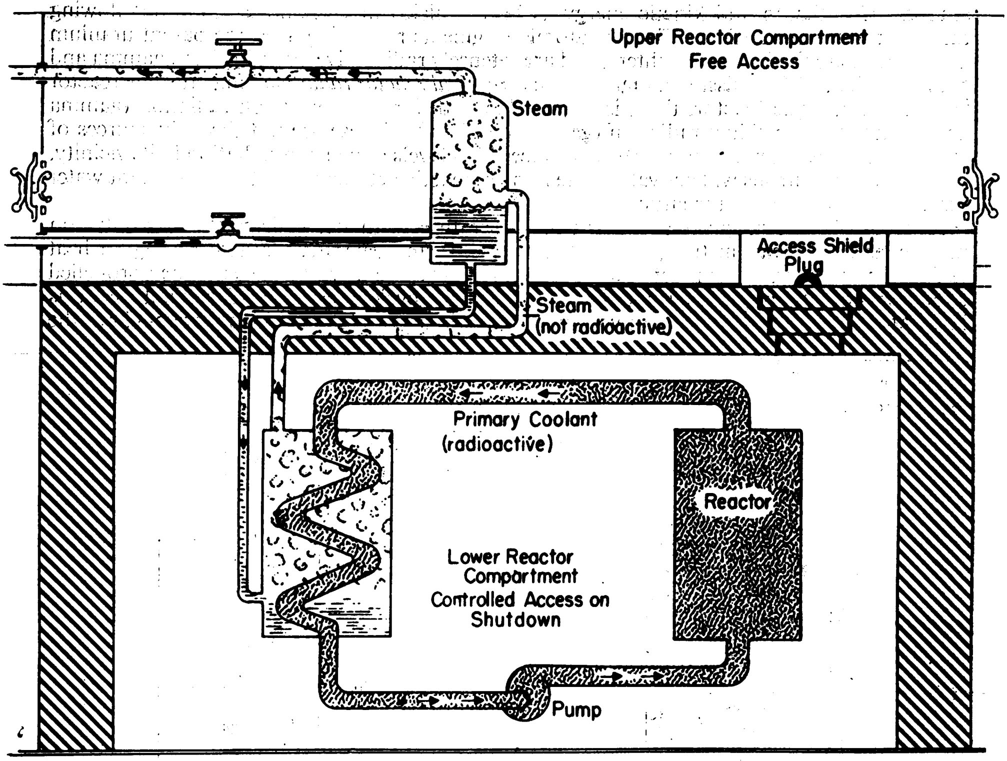

FIG. 4.—Reactor and its shielding.

Note from Fig. 4. that the upper reactor compartment sees no contaminated coolant water, only non-radioactive steam. Some gamma and neutron radiation will enter the upper level through the shield when the reactor is operating, but not in any degree which prohibits working in or manning the upper compartment. The highest level of radiation in the upper compartment is above the reactor area and sharply falls off with distance from that point. Levels in the after section of the upper compartment at full power, for example, are of the order of only 5 mrem per hour.

It must be emphasized that the reactor compartment is the only area on the ship where a radiation flux exists. All other compartments are similar to those on conventional submarines. Outside of the reactor compartment, crewmen, when submerged, receive less radiation than when ashore, due to the shielding effect of the water on cosmic radiation. This effect is noted on background radiation which decreases to a third of surface values with increases in depth of the submarine.

To return to the lower reactor compartment—the majority of the radioactivity in the coolant water has a short half life, and, because of its rapid decay, the lower area can be entered after reactor shut-down. While some reactor residual radiation remains, the chief source of radiation is gamma from the "plate-out" activated atoms inside the piping. Normally, there will be no exterior contamination present unless the system has been opened previously and contaminated coolant water spilled. Prior to entry into the lower reactor compartment after reactor shutdown, ship's personnel are preceded by medical department members who survey and monitor the area, checking for surface contamination, air-borne radioactivity, and degree of potential exposure. Permissible stay times in the lower compartment are determined and requirements for protective clothing formulated from this information. Monitoring stations are also established at exit points from the compartment and personnel leaving the area carefully checked for contamination. The monitoring points are also used as change areas if protective clothing is required.

RADIATION EXPOSURE LIMITS—THEIR MEANING

One of the often misunderstood aspects of radiation exposure is a faulty concept of maximum permissible exposure levels, particularly in relation to presence or absence of clinical findings. In dealing with any potentially toxic material industrially, be it lead, organic solvents, or radiation, it is necessary for operational purposes to compromise between zero exposure and the levels known to cause detectable biological effects. This compromise value, often called tolerance, is usually placed well below the threshold of minimum clinical change by a large factor—providing a threshold clinical response is typical of the toxic element in question.

In arriving at such a maximum permissible value, one uses historical observations, human clinical data, animal experimentation and laboratory data. For continuous industrial application the permissible exposure arrived at must be well below the threshold known to produce detectable change even if the exposure should last over the entire work life of the individual. This is usually accepted as being thirty years in duration.

Since for many clinical effects the rate of exposure is equally as important as the total integrated amount received over a given period, permissible levels may be expressed in terms of a rate. In the case of radiation the rate of total body exposure rather than the total dose is the more important, except for genetic, and possibly longevity effects. For example, 40 roentgen of total body gamma radiation received over a period of eight years will produce no effect on hæmatology of the individual, yet the same dose, if delivered in minutes, will produce demonstrable findings. In this latter case the time-dose relationship is such that the rate of tissue regeneration is exceeded by the rate of tissue damage.

The permissible exposure basically used in shipboard shielding design is 300 mrem per week measured in air. Note that this is not a wartime, or single emergency, or casualty exposure, but an industrial type application for continuous operation over a work lifetime. If 25 to 40 rem total body radiation is required as the threshold dose to initiate leukopenia—one of the most sensitive of biological indicators—it is obvious that one cannot depend upon clinical laboratory procedures to control radiation exposure at or below the 300 mrem/week tolerance level. In the hæmatological example the threshold of a sensitive biological indicator is 150 times greater than the maximum allowable weekly exposure of 300 mrem, far too high to be of any value.

The important and often misunderstood point is that *personnel exposure control and exposure measurement at or below tolerance levels is entirely dependent upon instrumentation. Clinical laboratory procedures are of no value in this regard.* This point is emphasized because of the repeated questions, not limited to laymen, concerning clinical findings in our personnel, particularly in relation to hæmatology. The lack of reality in these questions is obvious when the exposure pattern on "Nautilus" and "Seawolf" is analysed. This point is emphasized because of the potential danger inherent in the false idea that routine blood counts constitute a radiation hygiene programme. If such a programme were mistakenly used as a control measure, gross over-exposure by present tolerance standards would result.

A second point that requires emphasis is that, since permissible levels are well below the biological threshold, cumulative effects by definition cannot occur, since rate of tissue and cellular repair will always exceed rate of damage. Note this holds true only for effects that show a threshold, and does not apply to such non-threshold phenomena as genetic change where cumulative effects can occur independent of rate.

The Exposure Record—"Nautilus" and "Seawolf"

The preceding statements become more emphatic when the personnel exposure data of "Nautilus" and "Seawolf" are analysed. At the presently accepted permissible exposure of 300 mrem per week, during the fifty-week period of one year a man may receive 15,000 mrem (or 15 rem). Recent recommendations from the National Committee on Radiation Protection may, in effect, officially reduce the weekly permissible exposure to 100 mrem per week. On a yearly basis this would be 5,000 mrem (or 5 rem) per man per year. Bearing the figures of 15,000 and 5,000 mrem per year in mind, note the following average exposures:

(1) "Nautilus" in 1955 .. .. 173 *mrem per man per year*
(2) "Nautilus" in 1956 .. .. 210 *mrem per man per year*
(3) "Seawolf" in 1957 .. .. 204 *mrem per man per year*

"Seawolf" exposure data is extrapolated from data obtained during the first six months of her first fully operational year.

These figures of average yearly individual exposure at their maximum represent 1·4% of the official permissible exposure and less than 5% of the proposed new permissible exposure level.

If, rather than the average exposure, the maximum individual yearly exposure is used a wide differential still exists between the actual level and the maximum permissible level. The following represent the highest individual yearly exposures recorded:

(1) "Nautilus" in 1955 .. .. 1,438 *mrem per year*
(2) "Nautilus" in 1956 .. .. 2,100 *mrem per year*
(3) "Seawolf" in 1957 (extrapolated) 1,126 *mrem per year*

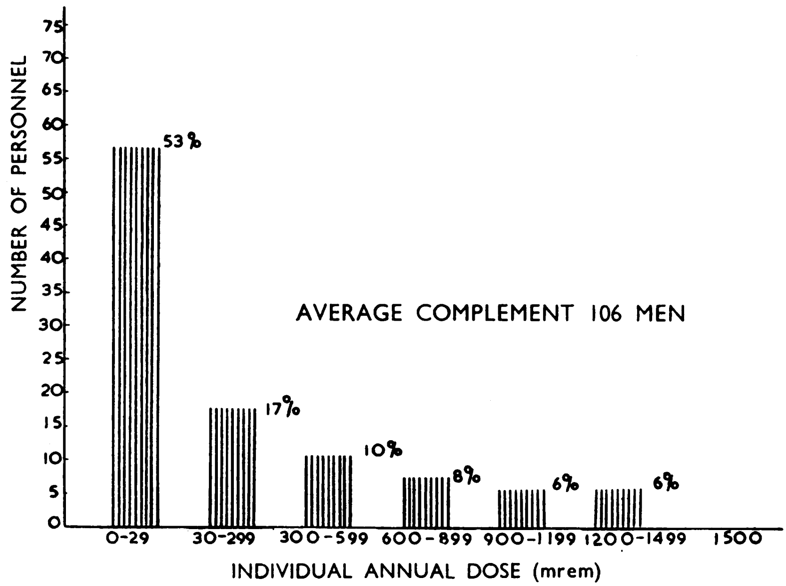

FIG. 5.—Distribution of individual exposure during 1955.

Taking the highest figure, these maximum exposures represent values of either 14% or 44% of the maximum permissible exposure per year.

Fig. 5 illustrates an important pattern of this exposure in depicting the distribution of yearly dose among the ship's population. It should be noted here that almost 50% of the crew receive no measurable exposure. The remainder of the crew spend varying periods of time in the reactor compartment and, therefore, receive some exposure. This is the only section of the ship where exposure can be received due to the conservative shielding practice described previously. The data shown in Fig. 5 is from the 1955 data of U.S.S. Nautilus but has held true since that period for both ships.

This exposure record serves to emphasize the fact that all of our experience to date is well below both the level of clinical effect and of maximum permissible exposure values.

INSTRUMENTATION

In the absence of any dependable clinical effect to quantitate human exposure our dependence upon instrumentation is great. The data given above, for example, were obtained from personnel film badges worn by all hands on board. Such personnel exposure is measured both by the film badge and pocket dosimeter. The ship maintains its own photodosimetry programme, including capability for full processing of the film badges. Radiation monitoring equipment, counter-scalers for sample counting, radiochemical equipment, radiation sources, film processing tanks, and other equipment are located in a small, compact laboratory under medical department cognizance duplicated in both ships. Figs. 6 and 7 show views of the laboratory. In addition to the concentration of analytical equipment in the laboratory, protective clothing, including filter masks and emergency radiation measuring devices are dispersed throughout the ship.

It has been emphasized that these instruments, rather than any known biological changes, are required to quantitate personnel radiation exposure at the sub-threshold levels encountered in nuclear submarines. Such equipment may appear deceptively simple in operation but requires a thorough knowledge of its limitations, capabilities, and eccentricities for maximum usefulness.

Let us analyse some of the general problems associated with personnel dosimetry in order to point out the pitfalls in using instrumentation. Consider, for example, the film badge and pocket dosimeter. These devices are worn by all the ship's personnel when aboard and form the basis for personnel exposure records. The film badge is a metal holder, divided into a shielded portion and an open window portion. This division of the badge into two sections allows the film contained in the badge to differentiate between beta and gamma radiation by the response of the portion of the film below the shield compared to that below the open window. This also allows for some differentiation of thermal and fast neutrons if the shield is cadmium or some other element which captures thermal neutrons. In the case of beta-

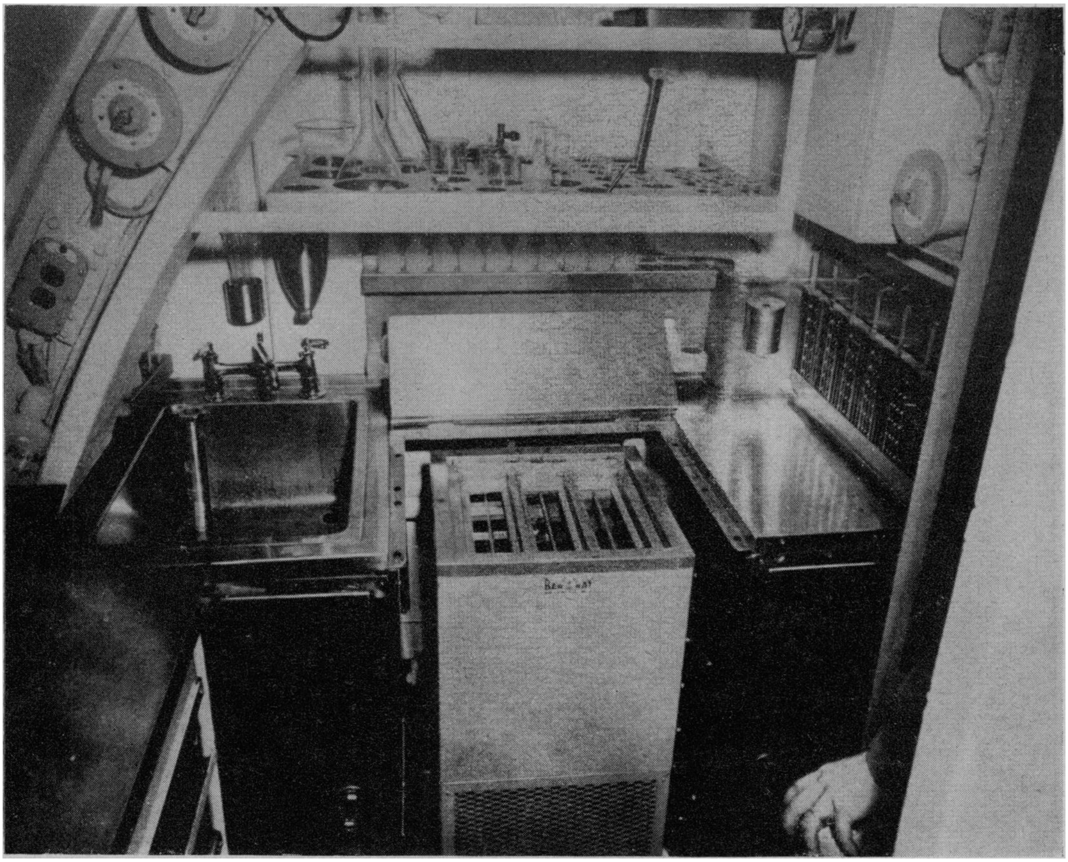

FIG. 6.—Radiation laboratory.

gamma radiation the film, after developing, presents a density proportionate to the amount of radiation seen. The degree of density of the emulsion is determined by a densitometer, and the density obtained referred to a density-dose calibration curve. The calibration curve itself is based upon exposure of several films to a known standard radiation source, determination of the density for each known dose, and plotting the results as a curve. Such a curve must be made on each batch of film used.

The pencil-like pocket dosimeter is a device much like a simple gold leaf electroscope. When held up to light a fibre is visible in the eye-piece against a small scale reading 0 to 200 milliroentgen. Ionizing radiation passing through the dosimeter removes an electric charge on the fibre causing it to move across the scale in the manner of the gold leaf in a discharging electroscope. The fibre can be reset to zero by re-charging the dosimeter after any desired time or dose interval. Removal of the charge, and hence a positive reading, can occur due to insulation leakage known as "drift". Usually this is at a very low rate, but must be determined on each dosimeter. Calibration against a standard radiation source is also necessary as with film. A characteristic of dosimeters is sensitivity to mechanical trauma—an important negative characteristic aboard a ship where rough treatment may be expected.

Many variables affect results and influence interpretation in both instruments. In the case of film, storage at recommended low temperatures is important. Film storage must also provide for zero radiation exposure which must be checked by processing control film. Calibration conditions for both devices must be carefully considered, including freedom from backscatter. Both film and dosimeters are energy-dependent, and for this reason the calibration source must emit energies approximating those to be met in the field, a difficult achievement. In the case of dosimeters, the drift rate must be repeatedly checked as insulation properties may change with time and environmental conditions.

If it is assumed that all of these factors have been adequately controlled, many important variables remain to be considered. First of all, both these devices will usually be worn

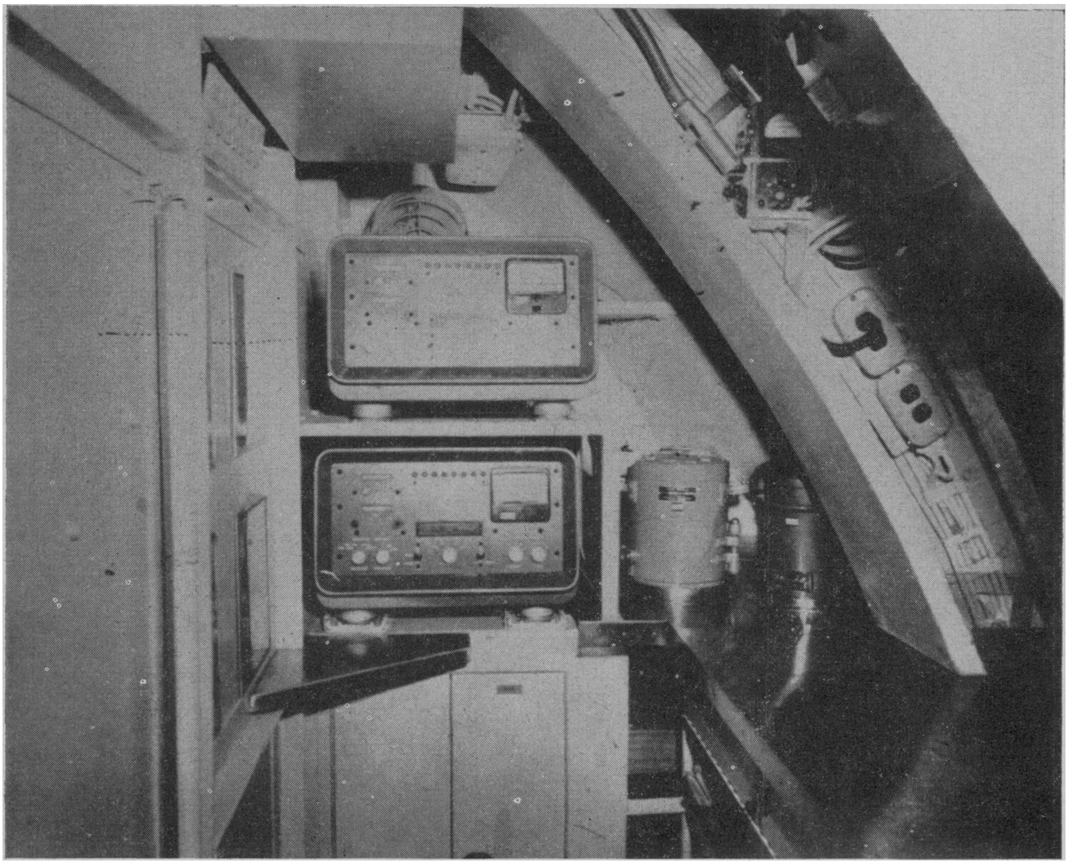

FIG. 7.—Radiation laboratory; another view.

clipped to the shirt front. In this position they do not measure a pure air dose as required by definition of the roentgen, but a complex dose disturbed by body backscatter. While one may minimize this factor by calibrating with a phantom, the angle of incident radiation in the field may differ significantly from that of the calibration situation; this is not a predictable variable within accuracy limits in the shipboard situation, but varies from position to position and with the attitude of the wearer.

If these factors are accepted, one faces an important problem in interpretation of the depth dose. The film badge is worn on the body surface and, as such, measures a surface dose which will be significantly modified by several centimetres of tissue before reaching a depth such as the median sagittal plane. The relationship between surface and depth dose can be computed, but the relationship will vary markedly with the energy of the radiation, with variation in tissue density due to presence of bone or air, and with angle of incidence of the radiation among other factors. A specific instance of large error, for these reasons, exists in those cases where the primary radiation enters posteriorly and the devices are worn anteriorly, a practical situation in lower reactor compartment work. An additional factor lies in the fact that, while total body exposure is the entity of interest, only a few square inches of body surface is covered by the film badge and dosimeter. A narrow beam may, therefore, be missed entirely, or, if detected, will be over-emphasized in relation to total body exposure.

If all of these possible variables and conditions are accepted, one is still faced with even further variables in the technique of film processing itself. These include control of purity of water used in mixing processing solutions, adequacy of darkroom conditions, and control of solution temperature during processing. Temperature control alone is a formidable problem and must be maintained rigidly throughout the processing solution with avoidance of any layering effect because temperature changes during processing will affect the emulsion as well as radiation.

Considering all of these many variables inherent in only two of the instruments used, it is not surprising that there is a search for some concrete biological change as a means of quantitating exposure to ionizing radiation. Interpretation of data obtained from such equipment requires a broad knowledge of both physical and biological factors. This is probably the strongest argument for the utilization of a medical officer in this field. Radiation is not an entity whose hazard can be simply evaluated by a glance at a meter or recording of a number, but requires careful consideration of many physical and biological factors. This is particularly important as a result of recent trends toward lower permissible exposure values, as instrument accuracy becomes more strained at the lower limits of sensitivity.

Medical Department Duties

The medical departments of both ships consist of a submarine medical officer and two hospital corpsmen, although more corpsmen may be assigned from time to time for training purposes. The medical officer, besides his regular submarine medicine training, will have received at least an academic year of training in nuclear medicine, and will usually have had several months' experience at an operating land-based reactor prototype. The corpsmen have received at least nine months of training in radiation hygiene techniques, and also participitate in the course in nuclear engineering given to all engineering ratings.

While at sea one of the three members is on watch in the laboratory at all times. During his watch he is responsible for following a schedule of various radiation checks. For example, every four hours portable air samples are taken in the engine room and reactor compartment and processed in the laboratory, several check points in the reactor compartment are spot-monitored for gamma and neutron radiation levels as a check on shield integrity, constant monitoring equipment through the ship is checked, read, and recorded every watch, liquid samples from various portions of the engineering plant are processed and counted on a watch basis in order to maintain a constant record of radioactivity present. All radiation measuring devices must be checked daily for accuracy with standard radiation sources. Weekly, all compartments are wipe-sampled as a check on surface contamination. Every two weeks personnel film badges are collected, processed, and results recorded. When submerged, in addition to the radiation measurements, determinations of oxygen, carbon dioxide, carbon monoxide, and other gases are made every two hours.

During in-port periods if work is scheduled in the lower reactor compartment, particularly if disassembly of the system is involved, the workload increases markedly. For, in such a period, the control of contamination in the confined space of a submarine represents a great challenge. In such a period monitoring points must be manned, work times determined in radioactive areas, protective clothing requirements decided upon, and transport of contaminated material supervised. Decontamination facilities may have to be established. The situation is never static. Each task requires its own analysis and solution.

The Future

The problems of the future with the expansion of the nuclear navy are:

(1) Need for extensive training of personnel and development of shore-based facilities for handling repair and maintenance of nuclear ships, especially in processing of contaminated equipment on the ship and on the base; establishment of dosimetry and monitoring facilities for contaminated laundry; use of material decontamination techniques.

(2) Development of more accurate instruments for relating radiation measurements to true biological dose, particularly in the field of neutron flux measurement.

(3) Development of long-term training programmes for both officer and enlisted medical personnel in the field of radiation hygiene.

(4) Continuing research on the effects of prolonged submergence, particularly in the identification and quantitation of all atmospheric elements built up under such circumstances.

But these are problems limited to the navy where nuclear power is in being rather than in potentiality—what of the significance to the civilian medical profession as a whole? A recent article in *Nucleonics* magazine, demonstrates the dramatic increase in the number of operating civilian reactors by 1960. With such acceleration medical problems are bound to appear in this area, and can potentially involve all of us, if in nothing more than in allaying the chronic semi-hysterical outlook of the public in any matter concerning nuclear radiations.

Nuclear power is the most promising development to meet the challenge of diminishing fossil fuel supplies. The events in the Middle East stress the World's dependence upon fossil fuels and the consequences of any diminished supply of them. Yet, diminish they must, and at a rapid rate by the early twenty-first century, with consequent lowering of industrial potential and standards of living if substitutes are not available. Great Britain has already launched a large-scale civilian nuclear power programme.

Specifically, the physician interested in industrial medicine will be deeply involved in evaluating and establishing future radiation control programmes, the traumatic surgeon may find wound contamination a new factor, the ophthalmologist will be used in physical screening of personnel for posterior subcapsular opacities, the internist will be involved in diagnostic problems, not the least of which may be emotional in origin in relation to radiation; hæmatologists will also play a part.

We must not, then, consider this a limited field, confined to a handful of military specialists; but a field of potential future significance to us all. Apart from the specialized problems mentioned, the profession should be cognizant of this technology and its effects simply to answer the questions from a public beleaguered with conflicting statements related to weapons and weapon effects, so often confused with reactor radiation problems.

It would seem prudent to incorporate such subject matter into medical school curricula as soon as possible, and perhaps into present industrial medicine courses, perhaps as part of radiology, by any method which will assure our capability of dealing with the problem.

Discussion

In reply to a large number of questions by **Squadron Leader T. C. D. Whiteside, Air Commodore D. A. Wilson, Dr. B. W. Soole, Rear-Admiral G. A. M. Wilson, Dr. D. W. H. Barnes, Mr. D. E. Barnes, Professor G. P. Crowden, Surgeon Captain C. B. Nicholson** and others, **Lieutenant-Commander Ebersole** said that body odours were overcome largely by the use of the filtration units already installed for removing CO_2 and CO from the atmosphere and by the submarine's ventilation system. The crew also became immune to the residual submarine odour during a long cruise, although others became aware of it when they went ashore. Dispensing with diesel propulsion had not changed this characteristic submarine smell which permeated clothing and was probably contributed to by a number of chemical factors which had not as yet been identified.

He was convinced of the need for the Naval Medical Department to be given full responsibility for the control of the environmental factors, including the radiation hazard, which were encountered during prolonged submergence in nuclear-powered submarines especially during the developmental period. This allocation of responsibility might not hold, however, for nuclear-propelled surface ships. The engineers had their hands full with their own technical problems in submergence and it would be unfair to expect them to give the necessary weight to the human factors which these obviously merited; and they might at times "rush in where angels fear to tread!" The commanding officer needed the authoritative advice of a medical officer who was technically familiar with the many complex problems involved, particularly as the total situation had not yet been evaluated.

In the United States Navy submarine medical officers and hospital corpsmen were trained in submarine physiology and plant construction as part of their initial course of instruction before they volunteered for nuclear-powered submarines and underwent further training. They had to know the component parts of the engineering plant and even to take part in routine watchkeeping duties. This additional training had paid off time and again during the development stage and early operations of U.S. Submarines Nautilus and Seawolf.

In reply to Dr. Soole Lieutenant Commander Ebersole said that saturated caustic soda was used for fission product analysis in place of ammonia hydroxide—a nasty substance to handle in a rolling submarine. Mineral acids were substituted for volatile organic acids such as glacial acetic acid. Pulse height analysis was not used for identifying specific isotopes. There were at present difficulties in the use of scintillators which might be overcome.

The neutron problem was first tackled by the contractor who was required to shield the reactor to ensure that not more than 10% of the radiation dosage was due to neutrons. The B.F.3 tube instruments for thermal neutron estimation and Radioactive Products Incorporated Model E.1 fast neutron dose rate meter were used as routine monitoring instruments. Neutron film badges (Eastman Kodak N.T.A. emulsion of 40 micron thickness) were always worn but they were only developed if the gamma dose exceeded 200 mr in a two-week period.

Neutron film development was more complex than estimating gamma dosage, as it involved the use of a microscope and oil immersion techniques.

In reply to Dr. Barnes he showed a picture of the ship's sick bay which was kept quite separate from the radiation laboratory. There was, however, very little sickness in submarines apart from the customary respiratory epidemics at the beginning of a cruise before the crew became immune to each others' strains. The number of injuries sustained on the bridge on the surface in conventional submarines was greatly reduced in nuclear-powered submarines which spent very much longer periods submerged.

In reply to Mr. Barnes he pointed out that radiation dosage was not a function of the shield entirely, as the greater exposure occurred during maintenance periods when men were beneath the shield. Little was to be gained by shaving a small amount of lead off the shield under existing circumstances, especially as at a later date the submarine might well be required to carry a large amount of lead ballast when it went to sea, a fraction of which could have been incorporated in the shield. There would be a gain from reducing the size of the reactor compartment but this would also reduce the accessibility of the component parts within it.

The effects of long-term exposure to carbon dioxide had been investigated before "Nautilus" did a prolonged dive in a submarine hull moored alongside in New London. Upwards of 20 men were exposed to 1·5% CO_2 in air for six weeks without any gross ill-effects being observed. But, the ideal was to provide the submariner with air that approximated to atmospheric air in composition as nearly as possible. In his opinion 1% CO_2 was a far better upper permissible limit to consider, particularly if smoking was to be allowed, for carbon monoxide potentiated the effects of carbon dioxide.

In conclusion, the **President** thanked Lieutenant Commander Ebersole for his most valuable address and for coming from the U.S. Submarine Seawolf to speak to the Section.